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LUNAR DUST TOLERANCE TESTING OF REPRESENTATIVE SEALS FOR LUNAR SURFACE HATCH SEALS

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INTRODUCTION:

The Moon's surface creates a uniquely challenging environment for mechanisms and materials. Electrostatic adhesion combined with a jagged particulate morphology makes lunar dust particularly destructive to the components and sub-systems of lunar surface assets. One component that will be acutely impacted by lunar dust is seals, particularly those on the hatches which will be opened and closed to allow extravehicular activities (EVA) and on docking systems that will connect surface assets and spacecraft together. Lunar dust on these seals can create leak paths for the pressurized atmosphere of a surface asset to escape. Quantifying the level of lunar dust contamination that is allowable for seals is of paramount importance for mission planners and asset designers. This paper covers dust tolerance testing that was conducted on representative hatch seals with the Uniform Dust Deposition System (UDDS) at NASA Glenn Research Center [1]. Sub scale (≈30 cm diameter) versions of seals for the Orion docking hatch and NASA Docking System (NDS were coated evenly with varying amounts of lunar dust simulant to evaluate its effect on seals leak rates. The resulting leak rate results from these flight-proven seal design can help planners and designers construct robust missions and products.

Lunar surface assets hatches with pressure seals will need to operate in the dusty, thermally extreme, lunar environment. State-of-the-art NASA docking system (NDS) and Docking Hatch Seal (DHS) sub-scale seals were contaminated with JSC-1a lunar simulant to evaluate their sensitivity to dust. The seals were then flow tested to evaluate the contamination's effect on their leak rates.

OBJECTIVES:

What seal contamination level causes seals to leak more allowed by requirements at room temperature?

What effect does temperature have on seal's ability to hold pressure when contaminated?

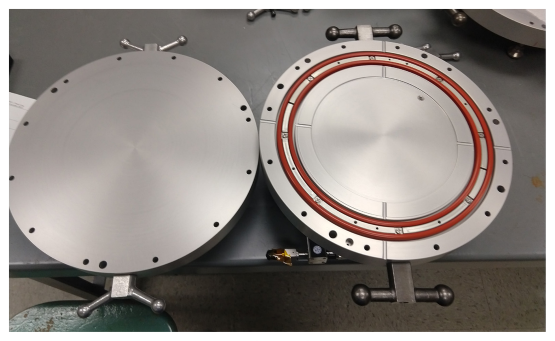

Figure (1): Leak test flow fixture with subscale NDS seal

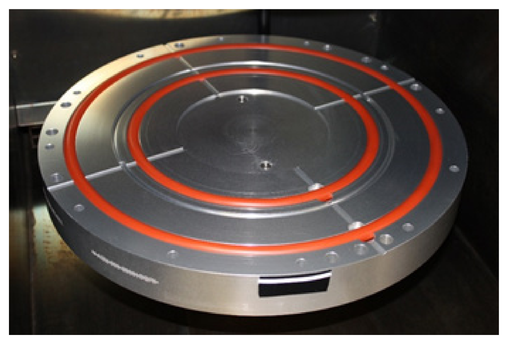

Figure (2): Leak test flow fixture with subscale Docking Hatch seal

METHODOLOGY:

Setup

For this testing both seal geometries (NDS and DHS) were installed in test fixtures with flight representative grooves. These seals were 13 inches in diameter and have identical cross sections to the seals used on NASA's Low Impact Docking System and Lockheed Martin's Orion capsule. Once installed the seals were leak checked once prior to dust loading to provide a baseline leak rate which could be compared against the contaminated leak rate.

Contamination

The JSC-1a simulant for this testing was pre-sieve to only contain particles smaller than 250 μm and was baked out per ASME D2216 to remove any moisture [1]. This particle size distribution was selected since it was assumed that larger particles would either not remain adhered or the crew would be compelled to clean them before closing a hatch [2]. The simulant was then loaded into the Uniform Dust Deposition System (UDDS) at NASA Glenn Research Centers [3]. The chamber was purged down to a relative humidity under 0.5 percent before introducing the seal installed in the lower half of its flow fixture. The UDDS then deposited controlled amounts of simulant onto the perimeter of the seal by rotating it under its deposition column.

Evaluation

Once contaminated the seal is automatically transferred to an imaging station where a microscope takes an z-stacked image at eight locations around the perimeter of the seal. The images are then feed through a ML algorithm that counts the particles on the surface and produces a percent coverage measurement [4]. The fixture with the seal is then removed from the UDDS and the top plate of the flow fixture is installed and torqued to flight requirements. The seal is then inserted into an environmentally controlled chamber and flow tested to evaluate the contaminated leak rate. For the thermal cycling tests the fixture was evaluated at room temperature then cooled to -50°C to conduct another leak test at that temperature. After, the fixture was heated to 77°C and the final leak test was run.

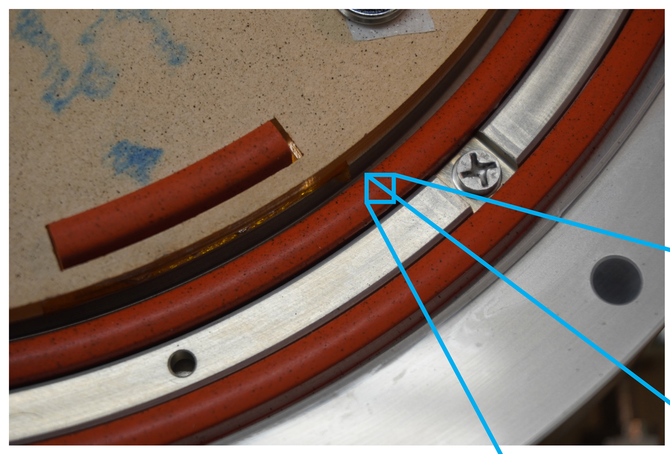

Figure (3): Contaminated NDS close up

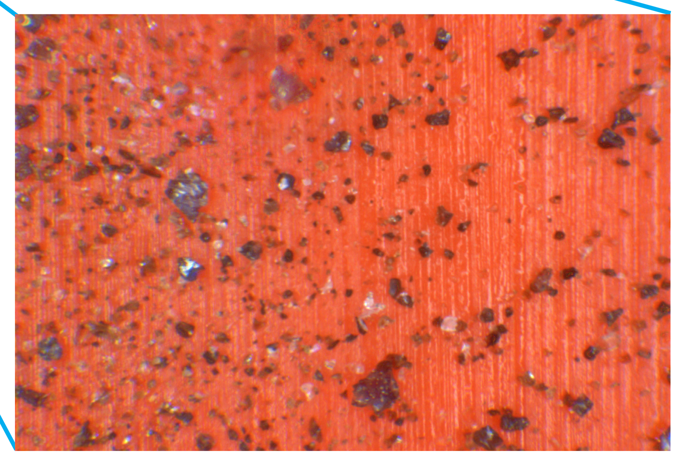

Figure (4): Micrograph of a NDS seal contaminated to its breakthrough level of 22% coverage

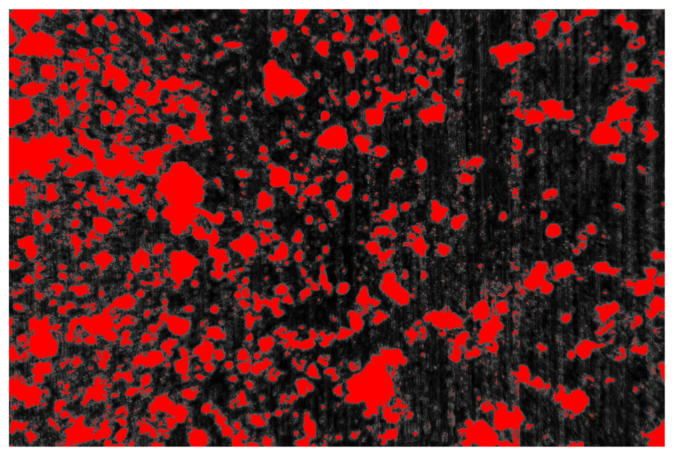

Figure (5): Segmented micrograph (50x) of a dusted seal at 22% coverage

RESULTS:

Breakthrough Point Test Results

During this testing campaign 15 NDS and 10 DHS seals were evaluated at room temperature over a range of contamination levels. The range of contamination levels was to be large enough to include marginal increases in leak rates, the breakthrough point, and catastrophic failures. The breakthrough point was defined to be the max contamination level that was present on a seal that would cause it to fail its leak rate requirement. It is to be noted that the leak rate requirements for both seal designs were different, 2.7e+3 ng/s for the NDS and 7.3e+4 ng/s for the DHS which themselves represent a 18.7x and 190x increase from baseline leak rates respectively.

The lighter max contamination levels of less than 14% for NDS and 10% for DHS represented between 1-2 times the increase in leak rates from the base line. These lighter levels help quantify the levels of contamination that the two seal designs would be allowed to sustain without any dust mitigation efforts being needed. This quantification could be done via optical image analysis in situ on the lunar surface.

The median deposition ranges between 14% - 22% for the NDS and 10% - 14% for the DHS designs helped determine the breakthrough point. The upper bound if this range yielded the breakthrough point which was approximately 22% for the NDS and 14% for the DHS designs. The transition from the passing contaminations past the breakthrough point was catastrophic in nature. The leak rates increased exponentially after their breakthrough points resulting in leak rate orders of magnitude higher than their allowable requirements as shown in figures 6 and 7. A couple of test seals were evaluated above the breakthrough point in the heavy deposition range to confirm the behavioral trend.

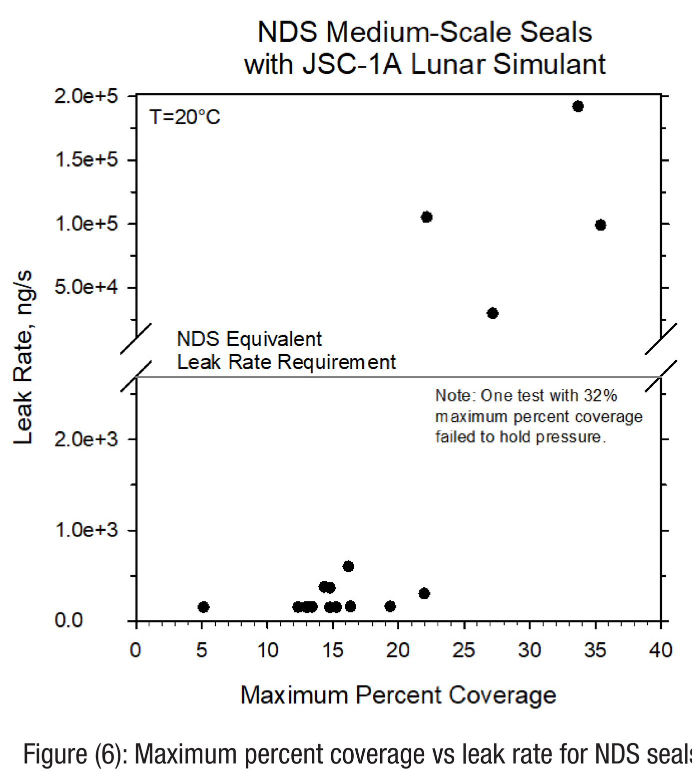

Figure (6): Maximum percent coverage vs leak rate for NDS seals

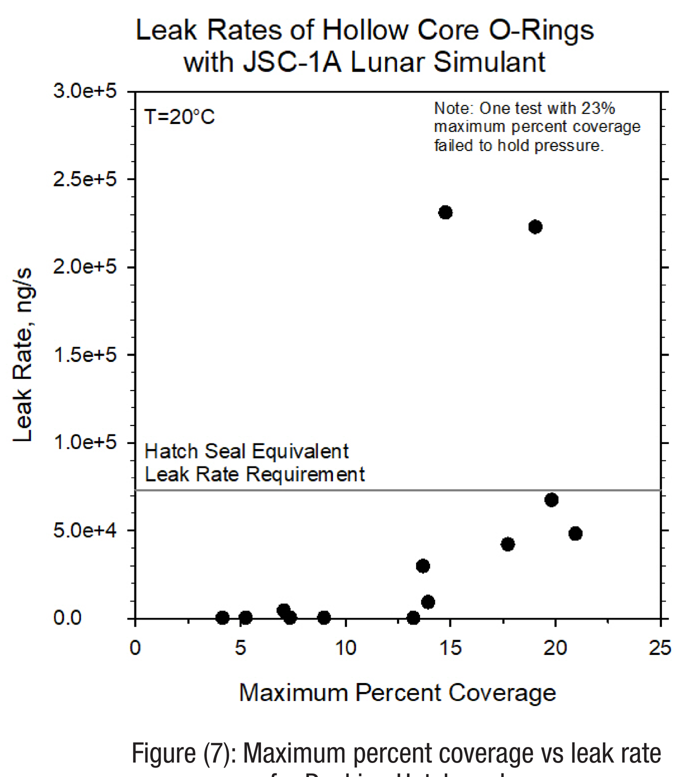

Figure (7): Maximum percent coverage vs leak rate for Docking Hatch seals

Thermal test results

For the thermal testing portion of this campaign four seals of each design were evaluated over three temperatures. Two seals of each design were coated with a light contamination level well below their breakthrough point and the remaining two were coated just under their breakthrough point. The lighter contamination was done to evaluate the effects of temperature on a leak rate that was well under the requirement. The contamination level just under breakthrough was selected to see if temperature could have a positive effect on seals that were near their leak rate requirement. The seals were contaminated, and first leak tested at room temperature in the environmental chamber to ensure a passing leak rate was achievable. The test fixtures were then cooled to -50°C and allowed to reach a steady state temperature before another leak test was conducted at the cold temperature. Following the cold test, the seals were heated to 77°C without removal from the environmental chamber. Once a steady state temperature was reached the final leak test was run and the testing was complete for that seal. This process was the same for both the NDS and DHS designs.

Over the course of this testing, it was noted that at lower temperature the seals would fail their leak tests while at higher temperatures they seem to meet their requirements easier [figures 8,9]. The hypothesized behavior causing these results is believed to be the stiffening and contraction of the seals at lower temperatures. It is possible that the cold seals resist the envelopment of the dust particles at lower temperatures creating larger leak paths. This could become exacerbated by the thermal contraction of the seals. However, these are only hypothesis and remain to be proven as the causes for the increased leak rates.

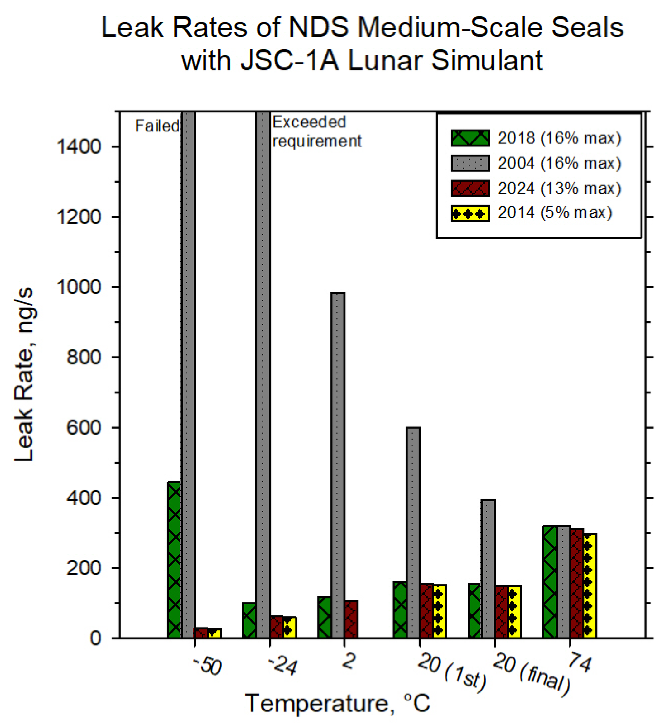

Figure (8): Temperature vs. leak rate for NDS seals

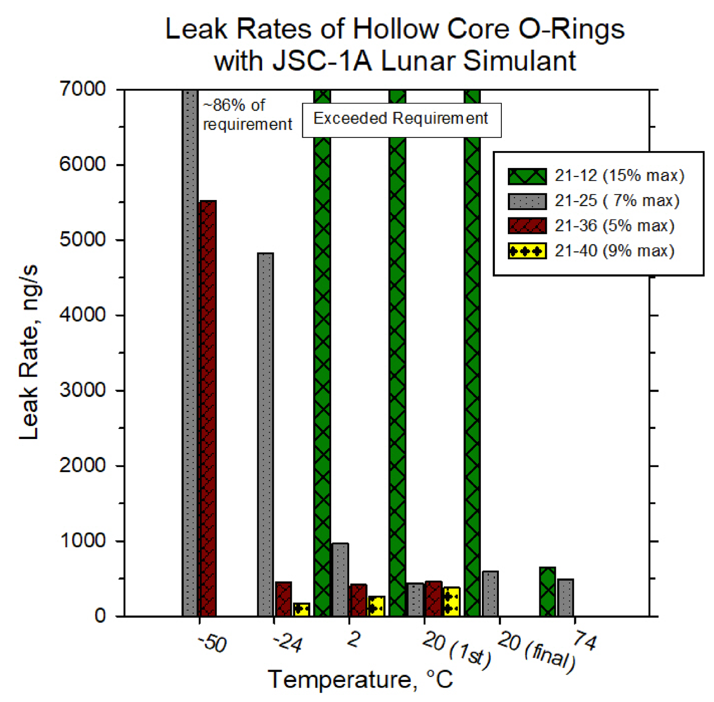

Figure (9): Temperature vs. leak rate f or Docking Hatch seals

CONCLUSIONS:

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This testing was successfully able to determine the breakthrough contamination level for two seal designs (NDS and DHS) at room temperature. From that testing it was revealed that the design of a hatch seal can greatly impact the allowable contamination level. In the case of the two design evaluated the NDS seal could tolerate ###% more contamination than the DHS, when compared to each of their leak rate requirements. The failures near the breakthrough points were catastrophic in nature and dust mitigation strategies should be employed at or near the breakthrough points.

The thermal testing was able to demonstrate that colder temperatures will cause elevated leak rates in any design of seal. Future testing will evaluate the effects of various cleaning techniques, surface treatments, and novel mitigation techniques for these seal designs near or above their breakthrough contamination levels.

ACKNOWLEDGEMENTS:

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References:

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[2] John, Kristen Kathleen; and Rogers, Charles E.: Classifications and Requirements for Testing Systems and Hardware to be Exposed to Dust in Planetary Environments. NASA–STD–1008, 2021.

[3] Gerdts, S., Jimenez, N., and Dunlap, P.H., "Lunar Simulant Deposition Technique for Dust Tolerance Studies," NASA/TM-2021-0024128, 2022.

[4] Arganda-Carreras, I., et al.: Trainable Weka Segmentation: A Machine Learning Tool for Microscopy Pixel Classification. Bioinformatics, vol. 33, no. 15, 2017, pp. 2424–2426.